Design of Experiments Software Reduces Engines' Time to Market by Two-thirds

Dresser Waukesha designs and builds large, gaseous-fueled stationary engines for power generation and gas compression applications around the world.

Waukesha engines are preferred for some of the most challenging applications because of their well-deserved reputation for operating dependably on a wide range of fuel qualities and in widely varying environmental conditions. However, even Dresser Waukesha must be able to provide customers with performance guarantees that specific engine models will operate within site-specific parameters. That, in turn, requires mapping the performance of each of the company's engine models taking into account the full range of variables to which the engine could be subjected in a real-world installation. These variables include fuel quality, air/fuel ratio, temperature, humidity, altitude, load and exhaust after-treatment. Of course, testing an engine with every possible combination of factors under which it might be used is impossible.

In the past, the effort needed to develop reliable predictions of engine performance was a painstaking, detailed and time-consuming manual process. Originally, the company ran a large number of one-factor sweeps in which engineers varied one factor over a range of values and recorded the results, which included electrical output of a generator connected to the engine, fuel consumption, jacket water and auxiliary circuit water heat available for co-generation applications, and exhaust emissions. When the tests were completed, engineers used statistical analysis, previous data, experience and intuition to estimate actual performance under field conditions not actually tested. Predictably, the accuracy of this approach was limited by its inability to account for interdependencies between the factors.

A number of years ago, the development team adopted the design of experiment (DOE) approach to increase the accuracy of performance estimates and reduce the number of required tests. DOE, by varying the values of all factors in parallel, provides a statistically validated estimate of the results for every possible combination of the factors. This approach determines not just the primary effects of each factor but also the interactions between the factors. DOE also requires far fewer experimental iterations than the traditional one-factor-at-a-time approach and makes it possible to identify the optimal values for all factors in combination.

At first, Dresser Waukesha used manual methods to set up the experiment design and evaluate the resulting data. The biggest challenge was using regression analysis to develop equations based on experimental data that described the relationship between the factors and the responses.

This approach required manually fitting the different equation forms to the data set. It achieved the goal of increasing accuracy of the performance predictions and reduced the number of experiments required. But the manual data analysis process took weeks and occupied considerable time on the part of engineers who were needed for other tasks.

“We were convinced of the value of DOE but needed a tool that would enable us to reduce the time required for data analysis,” said Dennis Spaulding, Senior Development Engineer for Dresser Waukesha. “We looked at a number of statistical software packages that offered DOE capabilities but they typically seemed to be designed more for statisticians than engineers. They offered a wide range of statistical capabilities but required that most aspects of DOE experimental design and data analysis be performed manually.”

Ultimately, the company selected Design-Expert® software from Stat-Ease, Inc., Minneapolis, Minn.

“We liked Design-Expert because it is designed for subject matter experts who are not necessarily experts in statistical methods,” Spaulding said. “The software walks users through the process of designing and running the experiment and evaluating the results while offering an exceptionally broad range of DOE capabilities.”

Design-Expert automates the experiment design and statistical analysis aspects of DOE behind an easy graphical user interface. With the software, the time necessary for data analysis is reduced by about two-thirds, which significantly speeds up the process of bringing new engines to market.

To prepare for a recent introduction of a new engine, Spaulding designed an experiment to evaluate its performance over a wide range of conditions. He entered the factors and categories of results outlined earlier into Design-Expert and set up the software to design an optimal experiment to fit a quadratic model. Design-Expert generated a design with 84 runs.

Dresser Waukesha technicians then performed the runs. Each run took between one and two hours, including setup, bringing the engine up to operating temperature, stabilization, performing measurements and cooling down the engine. As each run concluded, results were entered into Design-Expert.

In a matter of seconds, the software generated equations that best fit the runs performed up to that point. Engineers viewed the results to identify trends as well as look for data points that did not fit into the model. In several cases, technicians were asked to rerun points that did not fit well.

Design-Expert software was used to develop models of engine performance, including maximum power output, engine emissions and fuel consumption. These models were then entered into a spreadsheet which was used by the application engineering group to predict the performance characteristics of the engine at a particular customer site.

“The DOE process, coupled with the user friendly Design–Expert software has helped us improve the accuracy with which we can predict operating characteristics of our engines at specific customer sites while increasing the speed with which we can bring new engines to market,” Spaulding concluded.

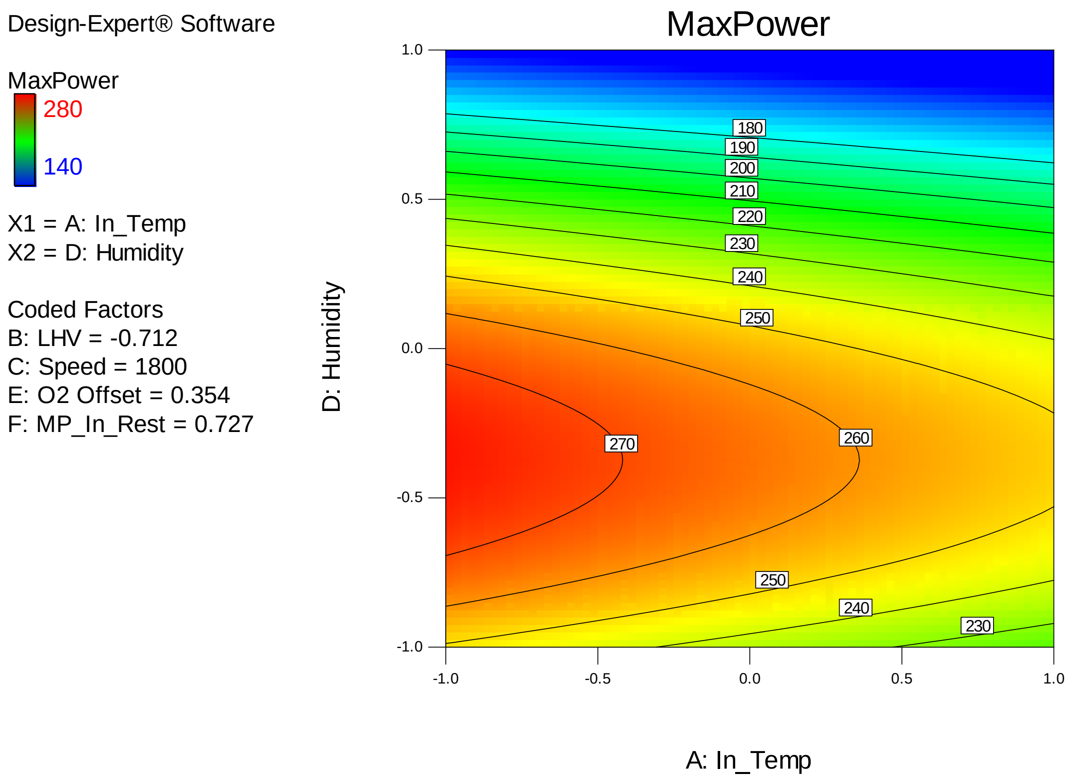

Figure 1: Maximum power as a function of humidity and inlet air temperature (factors coded for proprietary reasons)

Figure 1 above shows the maximum power prediction for a set of conditions as a function of humidity and inlet air temperature in coded values, for proprietary reasons. This prediction is important to understand because the ambient conditions from site to site, or even at a single site, can vary greatly. Figure 1 shows that the highest power output of the engine is achieved when the inlet temperature and humidity are both low. Inlet air is denser under these cool and dry conditions than when it is hot and damp allowing the engine to induct more air to burn with more fuel.

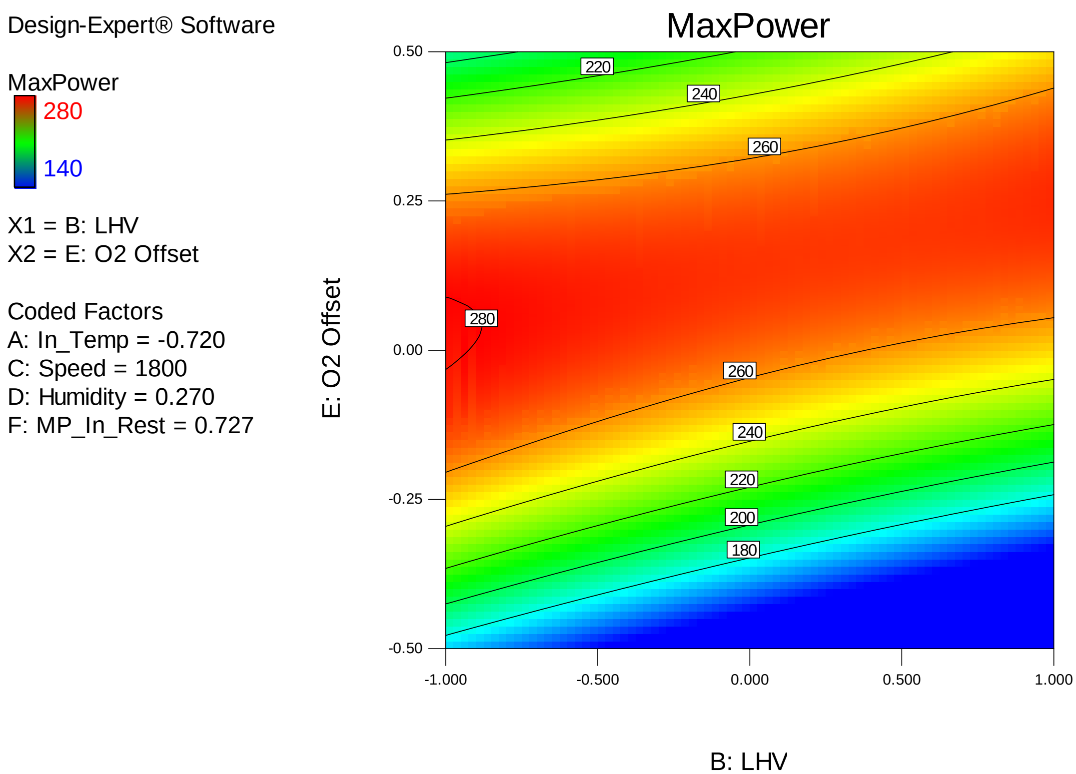

Figure 2: Maximum power as a function of fuel heating value and air/fuel ratio.

Figure 2 shows maximum power as a function of fuel heating value (LHV) and air/fuel ratio (O2 Offset) in coded values. Since the engine can be applied in applications that run on low energy content landfill or digester fuel gas in which the fuel quality can fluctuate, it is also important to understand how the fuel heating value and air/fuel ratio affect maximum power. Figure 2 shows that the air/fuel ratio required to reach the maximum power output changes with the lower heating value of the fuel. The lower the energy content of the fuel, the richer the air/fuel ratio must be to reach the same power output.

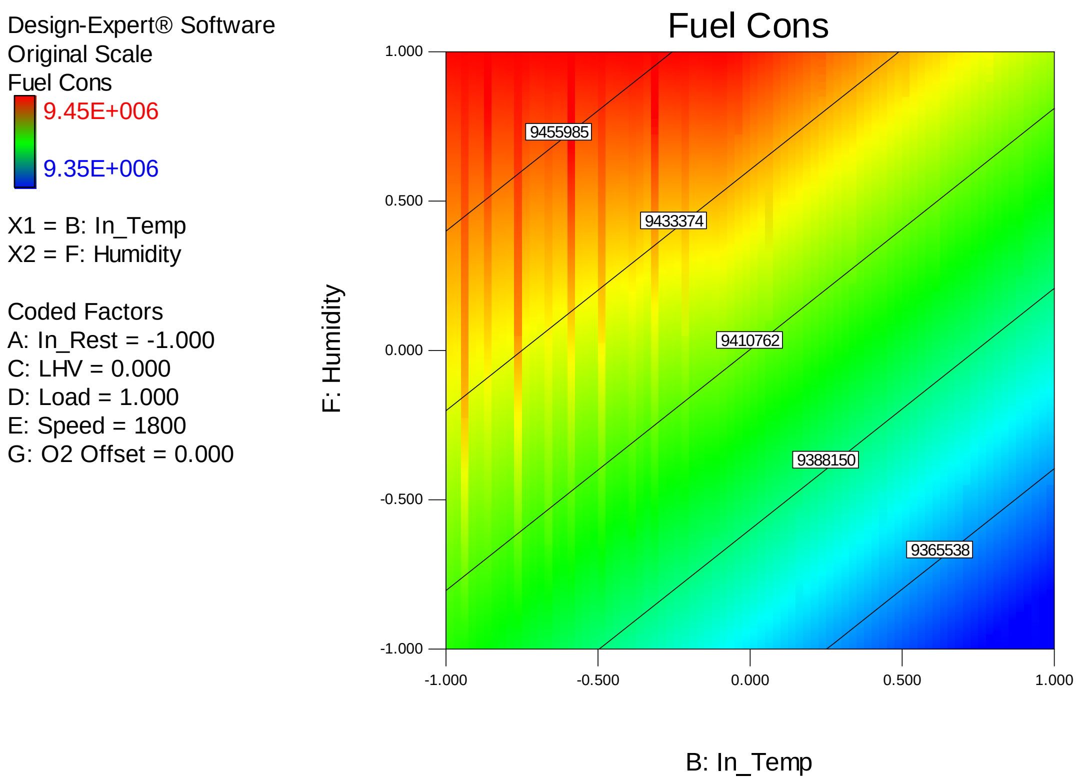

Figure 3: Fuel consumption as a function of inlet temperature and humidity

Figure 3 shows the relationship of inlet air temperature, humidity and fuel consumption.

It shows that fuel consumption is least when the induction air is hot and dry. When the air is cold, more combustion energy is required to heat the in-cylinder charge. Similarly, when the induction air is humid, water vapor in the air absorbs combustion energy.

Design-Expert® software automates the experiment design and statistical analysis aspects of DOE behind an easy graphical user interface. The software reduces the time required for DOE, enabling a substantial reduction in the time required for new engines to be brought to market.

For more information, contact:

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